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## Variable X-ray absorption in the mini-broad absorption line quasar **PG 1126-041**

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**Abstract.** We present the results of a multi-epoch observational campaign on the mini-broad absorption line quasar (mini-BAL QSO) PG 1126-041 performed with *XMM-Newton* from 2004 to 2009. Time-resolved X-ray spectroscopy and simultaneous UV and X-ray photometry were performed on the most complete set of observations and on the deepest X-ray exposure of a mini-BAL QSO to date. Complex X-ray spectral variability, found on time scales of both months and hours, is best reproduced by means of variable and massive ionized absorbers along the line of sight. In the highest signal-to-noise observation, highly-ionized X-ray absorbing material outflowing much faster ( $v_{out} \sim 16500 \text{ km s}^{-1}$ ) than the UV absorbing one ( $v_{out} \sim 5000 \text{ km s}^{-1}$ ) is detected. This highly-ionized absorber is found to be variable on very short time scales of a few hours.

## 1. Introduction

Accretion disk winds are among the most promising physical mechanisms able to link the small and the large-scale phenomena in active galactic nuclei (AGN), to shed light on the physics of accretion/ejection around supermassive black holes (SMBHs), and to help understanding the impact of the AGN phase on the host galaxy evolution (e.g. Silk & Rees 1998; Proga & Kallman 2004; Di Matteo et al. 2005; Booth & Schaye 2009).

Such winds are currently directly observed, as blueshifted and broadened absorption lines in the UV and X-ray spectra of a substantial fraction of AGN. In the UV band we observe broad absorption lines (BALs,  $\text{FWHM} > 2000 \text{ km s}^{-1}$ ), mini-broad absorption lines (mini-BALs,  $500 \text{ km s}^{-1} < \text{FWHM} < 2000 \text{ km s}^{-1}$ ), and narrow absorption lines (NALs,  $\text{FWHM} < 500 \text{ km s}^{-1}$ ) in about 30% of AGN, and their intrinsic fraction is estimated to be as high as 50% (Knigge et al. 2008; Ganguly & Brotherton 2008; Allen et al. 2011). These absorbers can be outflowing with speeds as high as  $\sim 0.2c$ . In the X-ray band, we observe lower-velocity ( $100\text{-}1000 \text{ km s}^{-1}$ ) ionized gas (the so-called “warm absorber”) in 50% of AGN (Piconcelli et al. 2005; McKernan et al. 2007). X-ray high-velocity absorbers outflowing with speeds up to  $\sim 0.3c$  (called ultra-fast outflows, UFOs) are observed in about 30-40% of local AGN (Tombesi et al. 2010). X-ray BALs, outflowing with speeds up to  $0.7c$ , have been also observed in a handful of AGN (Chartas et al. 2002, 2009; Lanzuisi et al. 2011). These observational results indicate that outflowing matter is a key ingredient of the inner regions of AGN, and that understanding the launching and structure of these winds is fundamental for constructing complete models of the central engine.

Here we present the main results of a multi-epoch *XMM-Newton* observational campaign on PG 1126-041, a low-redshift ( $z = 0.06$ ) AGN that shows UV mini-BALs blueshifted by  $2000\text{-}5000 \text{ km s}^{-1}$  in the C IV, N V, and Si IV species (Wang et al. 1999). An early *ROSAT* observation suggested the presence of ionized absorption as well as possible short-term variability (Wang et al. 1999; Komossa & Meerschweinchen 2000). The new *XMM-Newton* campaign provided the largest dataset (a total of four pointings: one archival in 2004, two in 2008, one in 2009) and the deepest X-ray exposure (133 ks in the 2009 observation) ever on a mini-BAL QSO. Our analysis confirmed the presence of massive ionized absorbers along the line of sight, and revealed complex spectral variability on time scales of both months and hours. We focus here on the variability of the X-ray absorbers; details on the X-ray analysis can be found in Giustini et al. (2011).

## 2. Complex X-ray spectral variability

The mini-BAL QSO PG 1126-041 shows complex and variable X-ray spectral properties. The average 0.2-10 keV spectra as seen by the EPIC-pn instrument aboard *XMM-Newton* during the four pointed observations are shown in the left panel of Fig. 1: most of the spectral variability on time scales of months occurs at  $E < 6 \text{ keV}$ . The long June 2009 observation (92 ks of contiguous net exposure time) has been split in four consecutive time intervals of 21, 30, 24, and 17 ks, where flux variations were evident. Spectra extracted from each time slice are plotted in the right panel of Fig. 1: strong spectral variability on time scales of hours affects only the  $E > 1.5 \text{ keV}$  part of the spectrum. It is evident that two distinct components are affecting the appearance and the variations of the X-ray spectrum of PG 1126-041.

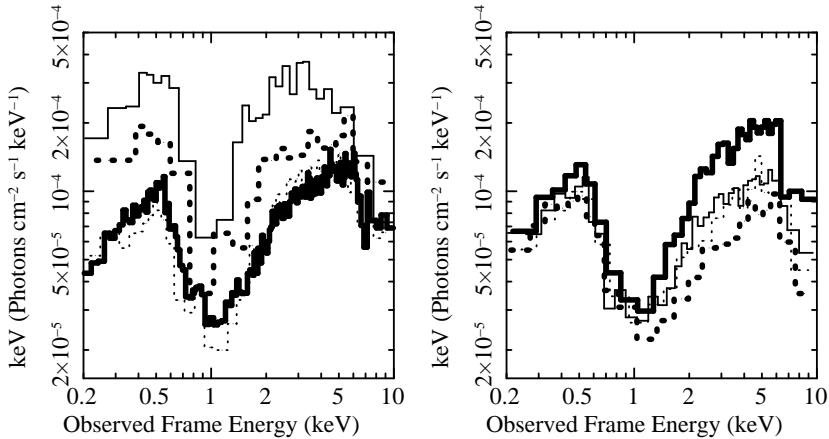


Figure 1. Left panel: unfolded  $F_E$  spectra of PG 1126-041, resolved on time scales of months; Dec. 2004 (thin dotted line), June 2008 (thick dotted line), Dec. 2008 (thin solid line), and June 2009 (thick solid line) spectrum. Right panel: spectra resolved on time scales of hours; four contiguous spectral slices of the 2009 long observation are plotted: first (21 ks, thin dotted line), second (30 ks, thick dotted line), third (24 ks, thin solid line), and fourth (17 ks, thick solid line) time interval.

In all epochs, the spectral shape is peculiar and obviously deviates from a simple power-law. A broad absorption feature is evident in all the four observations at  $E \sim 0.6 - 1.5$  keV, i.e. the energy range where X-ray warm absorbers mostly affect the spectral shape of AGN. Indeed a high-column density, moderately-ionized absorber is detected in every observation of PG 1126-041. The absorber column density ranges from a minimum of  $N_{m.i.} = 3.2_{-0.4}^{+0.7} \times 10^{22} \text{ cm}^{-2}$  (Dec. 2008 observation), to a maximum of  $N_{m.i.} = 1.5 \pm 0.2 \times 10^{23} \text{ cm}^{-2}$  (June 2009 observation; errors at  $3\sigma$  confidence level). Given the low spectral resolution of the EPIC-pn instrument, the gas ionization state is poorly constrained:  $\log \xi_{m.i.} = 1.55 \pm 0.15 \text{ erg cm s}^{-1}$  including the systematic uncertainties of the model parameters, therefore its possible variations on time scales of months can not be tracked. As a consequence of the X-ray absorption variability, the observed optical-to-X-ray spectral index is highly variable, going from  $\alpha_{\text{ox}} = -1.7$  in the Dec. 2008 observation, to  $\alpha_{\text{ox}} = -2$  in the June 2009 observation.

A highly-ionized absorber is clearly detected in the iron K band of PG 1126-041 during the long June 2009 observation. In particular, two deep absorption features at rest frame energy  $E \sim 7$  and  $\sim 7.4$  keV are identified with Fe XXV He $\alpha$  and Fe XXVI Ly $\alpha$  transitions, blueshifted by  $0.055c$  (see Fig. 4 of Giustini et al. 2011). The best-fit parameters for the highly-ionized outflowing absorber detected in the average 2009 spectra are  $N_{h.i.} \sim 7.5 \times 10^{23} \text{ cm}^{-2}$ ,  $\log \xi_{h.i.} \sim 3.4 \text{ erg cm s}^{-1}$ , and  $v_{out} \sim 16500 \text{ km s}^{-1}$ . Most interestingly, the highly-ionized absorber is found to be variable on very short (a few ks) time scales. Fig. 2 shows the spectral residuals in the iron K band referred to the four time slices of the 2009 spectrum to a model where the highly-ionized absorber was removed. Absorption in the iron K band is significant during the first  $\sim 20$  ks of the observation, disappears during the second time interval, reappears during the third, and then develops a complex and deep shape during the last  $\sim 20$  ks of the exposure, together with a strong continuum flare.

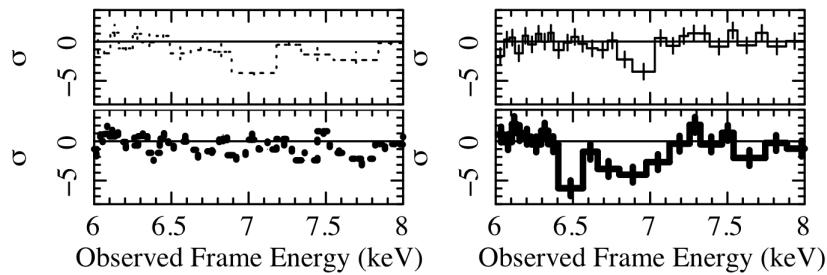


Figure 2. The 6-8 keV EPIC-pn spectral residuals in unit of  $\sigma$  of the four consecutive time slices of the long 2009 observation: first (thin dotted line), second (thick dotted line), third (thin solid line), and fourth (thick solid line) time interval.

The main driver of the PG 1126-041 spectral variability on month time scales is the variable column density of the moderately-ionized absorber ( $\Delta N_{m,i.}/\Delta t \sim 10^{22} \text{ cm}^{-2}/\text{month}$ ). The intensity of the intrinsic power-law emission is also found to contribute to the observed spectral variability, while the photon index  $\Gamma \sim 2$  is found to stay constant within errors between epochs. As for the spectral variability on time scales of hours, the constant flux at  $E \lesssim 1.5 \text{ keV}$  observed during the long June 2009 observation rules out variability of the moderately-ionized absorber. On the other hand, the highly-ionized outflowing absorber is found to be significantly varying over time scales of hours; however, it was not possible to assess whether it varied in ionization state, column density, or blueshift. The short time scale variability suggests that the absorber is very compact and close to the X-ray source, and that we are observing rapid mass ejections from the inner regions of the accretion disk. In any case, the observed short-term X-ray spectral variability of PG 1126-041 is dominated by variations of the intensity of the intrinsic continuum.

### 3. Conclusions

The *XMM-Newton* observational campaign on the mini-BAL QSO PG 1126-041 provided new results about the link of the accretion and ejection processes in AGN. Time-resolved X-ray spectroscopy performed on long and short time scales revealed the presence of massive and variable ionized absorbers along the line of sight, as well as a varying intensity of the intrinsic X-ray continuum. In particular, the long 2009 observation provided some of the best evidences of the transient character of high-velocity, highly ionized X-ray absorbing outflows over very short time scales of only a few hours.

The appearance of the X-ray spectrum of the mini-BAL QSO PG 1126-041 is dominated by variable ionized absorption. The variability of the moderately-ionized absorber is qualitatively consistent with the scenario depicted by Misawa et al. (2010), where a variable X-ray absorbing screen is invoked to explain the observed variability over (rest frame) week/month time scales of the UV mini-BALs in the QSO HS 1603+3820. Our observational findings are also consistent with UV line-driven accretion disk winds theoretical scenarios, where a thick, variable screen of X-ray absorbing gas (an overionized “failed wind”) close to the central SMBH shields the more distant portion of the flow from the strong ionizing continuum, and allows for its effective

acceleration (e.g. Proga & Kallman 2004). Indeed, the observed X-ray spectra of PG 1126-041 are quite similar to those predicted for highly-accreting AGN by the hydrodynamical simulations of Proga & Kallman (2004), as developed by Sim et al. (2010).

The strong variability of the highly-ionized outflowing absorber suggests that the assumption of constant velocity, usually used to estimate the mass outflow rate associated to the highly-ionized part of AGN winds, is likely to be incorrect: the dynamics of the inner accretion/ejection flow around SMBHs needs to be further investigated and, to this end, time-resolved X-ray spectroscopy is the most powerful tool that we have. Many exciting questions are still open: what is driving the variability of the ionized absorbers over different time scales? Is there any relation with the X-ray continuum flux level? What are the duty cycles of the ionized absorbers? Most importantly, how all this reflects on the mass outflow rate and on the energy budget associated to the wind? These questions may be tackled by means of long and deep X-ray monitoring campaigns of bright BAL and mini-BAL QSOs.

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